Journal of Forestry Research (2008) 19(3):204–208
DOI 10.1007/s11676-008-0043-2

RESEARCH PAPER

Growing stock variation in different teak (*Tectona grandis*) forest stands of Mizoram, India

Vinod Prasad Khanduri, Lalnundanga, J. Vanlalremkimi

Department of Forestry, Mizoram University, Aizawl -796001, Mizoram, India

Abstract: The growing stock assessment of three different teak forest stands (Tuirial: 500 m asl, Sairang: 200 m asl and Phunchawng: 550 m asl) was done in 2006 in Mizoram, India. Five diameter classes were arbitrarily established for knowing the volume attribute data and population structure, viz. a (10–20 cm), b (20–30 cm), c (30–40 cm), d (40–50 cm), and e (50–60 cm). Results revealed that the density of the individuals among the studied stands varied from 280 stems/ha to 620 stems/ha. The average diameter of all the individuals ranged between 27.48 cm and 35.43 cm. Similarly, the average height was oscillated between 17.87 m and 22.24 m. The total basal area was recorded between 24.28 $m^2 \cdot ha^{-1}$ and 45.80 $m^2 \cdot ha^{-1}$. The maximum and minimum values of total growing stock under all the diameter classes were 669.01 $m^3 \cdot ha^{-1}$ and 284.7 $m^3 \cdot ha^{-1}$, respectively. The representation of population structure of different stands explained that the perpetuation of this species was ensured for a quite long time.

Keywords: basal area; growing stock; population structure; stand density

Introduction

Teak (*Tectona grandis* Linn f.) is a large deciduous tree species that mature plants can reach 30 to 40 m height and 2 m diameter. It can grow in a wide variety of soils, tolerate a wide range of climates, and have best growth under the conditions that the minimum monthly temperature is above 13°C and the maximum monthly temperature is below 40°C. Optimal rainfall for teak ranges between 1 250 and 3 750 mm per year, however, for the production of good-quality timber the species requires a dry season of at least four months with less than 60 mm precipitation (Kaosa-ard 1981). Teak occurs on a variety of geological formations such as trap, limestone, granite, gneiss, mica schist, sandstone, quartzite, conglomerate, shale and clay (Tewari 1992). It usually grows on the soils with a pH range of 6.5 to 7.5. Below pH 6.0 it is absent and beyond pH 8.0 it suffers stress in growth. Altitude plays an important role in the plant growth. Normally teak does not grow at altitude of over 900 m and the plant vigour decreases over 750 m (Takle and Mujumdar 1956). Similarly aspects of the locality also affect the plant's growth and the plants grow better on the cooler northern and eastern aspects than on the hotter southern and western ones (Seth and Yadav 1957).

Received: 2008-03-18; Accepted: 2008-04-12

The online version is available at http://www.springerlink.com
Biography: Vinod Prasad Khanduri (1975), male, Reader in Department of Forestry, Mizoram University, Aizawl -796001, Mizoram, India (E-mail: vpkhanduri@yahoo.co.in)
Responsible editor: Hu Yanbo

The wood of teak is used for furniture, flooring, joinery, trim, doors, paneling, carving, musical instruments, turnery, vats, boat masts and decks, railway sleepers, mine props, fuel, and fence posts (Nair and Chavan 1985; Tiwari 1992; Bhat 1995; Brennan and Radomiljac 1998; Trockenbrodt and Josue 1998; Priya and Bhat 1999; Bhat 2000; Baillères and Durand 2000; Kokutze et al. 2004). The heartwood of teak is golden brown with a distinct grain and has a specific gravity of 0.55 (Longwood 1961).

Teak is native to India, Myanmar, Thailand, and Laos, and is the most important silviculture tree species in the tropics (Troup 1921). Teak is one of the most extensively planted tree species in the tropics, constituting about 6.0 million ha plantation area worldwide (Bhat and Hwan Ok Ma 2004). Approximately 94% plantations of this net area are located in Tropical Asia, with 44% in India and 31% in Indonesia. The plantations of other countries in the region contribute significantly with 7% in Thailand, 6% Myanmar, 3.2% Bangladesh and 1.7% Sri Lanka. The area of teak plantations in Tropical Africa is about 4.5% of total area of teak plantations and the rest are in Tropical America, mostly in Costa Rica and Trinidad and Tobago (Pandey 1998). The plantation forests of 5.3 million ha teak in Asian Pacific region have been managed under 35 to 80-year rotations, yielding 5 to 20 $m^3 \cdot ha^{-1} \cdot year^{-1}$, while 310 000 ha plantations in Africa are harvested at 20-year rotations, yielding between 4 and 13 $m^3 \cdot ha^{-1} \cdot year^{-1}$ (Bhat and Hwan Ok Ma 2004).

Growing stock is an important parameter required for sound forest management and planning. General information about the stock available per unit area is the key information desired for forest inventories, where the empirical diameter distribution of stand is not measured (Bhatt et al. 2002). The diameter distribution models are used to obtain estimates of tree size and distribution. The predicted distribution is needed for further computation

of stand volume characteristics using tree-wise height and volume models (Gray 1956; Larson 1963). The distribution of growing stock percentage under various diameter classes in even-aged and uneven-aged forests is an essential prerequisite for sound forest management practices (Paivinen 1980; Little 1983; Maltamo et al. 1995), the development of yield models (Nunifu and Murchison 1999; Corona et al. 2002; Bermejo et al. 2004) and estimation of carbon concentration (Kraenzel at al. 2003; Yamada et al. 2004).

Taking all the above facts into consideration, the present study is aimed to understand the structural attributes and growing stock variations in three different aged plantations of *T. grandis* established at different locations in Mizoram, India to forecast the harvests from existing plantations and to make management recommendations for the use in planning production.

Materials and methods

Study sites

This study was conducted in 2006 by selecting various plantations of teak in three different sites, viz. Tuirial (500 m asl), Sairang (200 m asl) and Phunchawng (550 m asl) of Aizawl district of Mizoram (Fig. 1). Mizoram is located at the extreme southern part of North Eastern Hill (NEH) region in India between 21°5' to 24°30' N latitude and 92°15' to 93°29' E longitude. The terrain is hilly and mostly undulate with the elevation range up to 2 300 m asl.

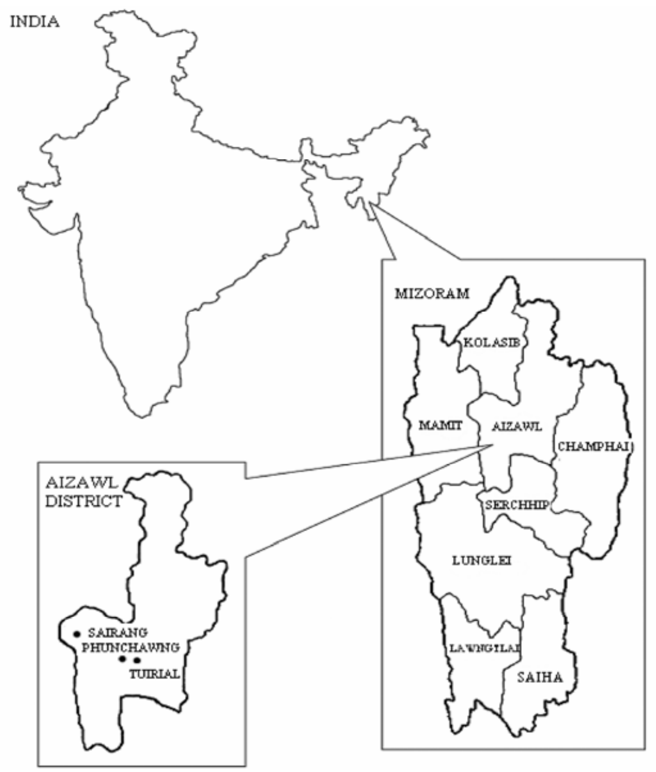

Fig. 1 Location map of the study area

Climate of study area

The climate of the area is characterized by high relative humidity nearly all year round and abundant rainfall. The cold season is from December to February, the spring and summer season from March to May, the rainy season from June to September and the rest, October and November constitute the autumn season. The records of rainfall reveal that it varies greatly from place to place. The annual rainfall of the study area during the last decade ranged between 1 850 to 2 090 mm. However, in the year 2006 it was quite low, i.e. 1 642.65 mm (Fig. 2). Rainy season contributes about 60 to 70 percent of the annual rainfall. Mean minimum and maximum temperatures of the study area in January were 11.16°C and 24.72°C, respectively, in June 17.71°C and 20.10°C, and in August 20.47°C and 28.63°C, respectively.

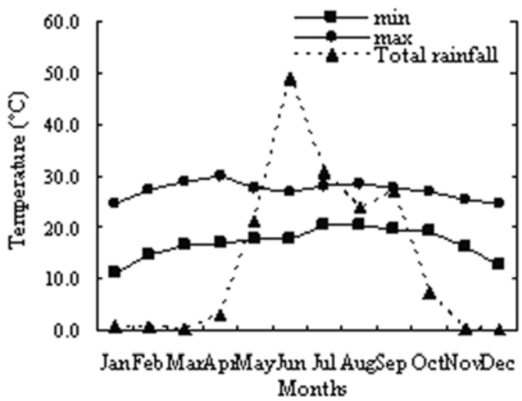

Fig. 2 Climatic diagram of the study region

Vegetation composition

The vegetation of this region is described as tropical moist forest (Champion and Seth 1968). Teak is growing as a monoculture in the three sites studied; however, the vegetation composition of the surrounding forest in different sites is different. At Tuirial the vegetation composition is *Gmelina arborea*, *Erythrina stricta*, *Ficus cunia*, *F. hirta*, *Michelia champaca*, *Toona ciliate*, *Terminalia tomentosa*. Sairang site exhibits *Artocarpus heterophyllus*, *Aegle marmelos*, *Bauhinia variegate*, *Cassia fistula*, *Melocanna baccifera*, *Schima wallichi*, *Sysygium cumini*. The forest composition at Phunchawng is composed of *Azadirachta indica*, *E. stricta*, *Erythrina indica*, *F. Cunia*, *Gmelina arborea*, *Sturculia villosa*.

Field methods and data analysis

The volume attribute data were obtained by using stratified random sampling techniques of the forest stands. The sampling of the forest stands was done by setting five sample plots of 0.1 ha size selected randomly in each site. The tree height and diameter at breast height were measured individually within the sample plots. The measurements of individual trees were summed as total volume for the plot. The measured data were extrapolated to

find the growing stock per ha in each site studied. To observe the population strength and area occupied by trees in each sample plot, the population density and basal cover were calculated as Curtis and McIntosh (1950) and Misra (1968).

The volumes of individual trees under different diameter classes, i.e., 10–20, 20–30, 30–40, 40–50, 50–60 and > 60 cm have been calculated by using the following volume equation adopted from the Forest Survey of India (FSI 1996). The general volume equation for teak is as follows:

$$V = 0.008690 + 0.323051 \times D^2 \times H \quad (1)$$

Where, V is the volume of individual tree, D the diameter at breast height, and H is the height of tree till the last branching

By means of statistical calculations the total timber volume was estimated for the entire forest. The output of statistical extrapolation will give only the numerical extrapolated timber volume for each stand. Summing up all individual trees gave the total timber volume existing within the sample plots. The summed timber volume in each sample plot has been calculated in terms of volume in cubic meter (m^3) per hectare. The operational equations for all computation of statistical means are as follows (Cochran 1977):

$$V_{sp} = \sum V_i \quad (2)$$

i = 1…n, number of tree measured within sample plot,

$$V_{ph} = v \times 10000 / a \quad (3)$$

where V_i is the volume of single tree, V_{sp} the total timber volume within sample plot, and V_{ph} the timber volume per hectare area under the sample plot.

The population structure in different sites was determined by using standard techniques of Curtis and McIntosh (1951). Five diameter classes were arbitrarily established for knowing the population structure, viz. *a* (10–20), *b* (20–30), *c* (30–40), *d* (40–50), and *e* (50–60). The number of individuals in a given size class was divided by the total number of individuals in all size classes, and multiplied by 100 to obtain percentage density for each size class (Knight 1975).

Results and discussion

A critical review on the data across all the sites revealed that the density of trees varied significantly among the sites. As shown in Table 2, the minimum density (280 stems/ha) was recorded at Phunchawng forest stand, followed by Sairang (410 stems/ha) and Tuiria (620 stems/ha) forest stands. The average diameter of all the individuals in each forest stand was maximum (33.25 cm) at Phunchawng forest stand, followed by Tuirial (30.43 cm) and Sairang (27.48 cm) sites. Similarly, the average height was also maximum for Phunchawng site (22.24 m) and minimum for Sairang site (18.67 m). The total basal area among all the studied sites was recorded as 24.30, 24.28 and 45.80 m^2/ha for Phunchawng, Sairang and Tuirial sites, respectively (Table 2). The maximum value (669.01 m^3/ha) of total growing stock under all the diameter classes was observed at Tuirial where maximum density (620 stems/ha) and total basal area (45.80 m^2/ha) values were also recorded and minimum growing stock values (284.7 m^3/ha) was recorded at Phunchawng site with the lowest density (280 stems/ha) and total basal area (24.30 m^3/ha) values (Table 2 and 3).

Table 2. Observed variables of stand features of *Tectona grandis* at three locations

Variables	Tuirial	Sairang	Phunchawng
Altitude (m, above mean sea level)	500	200	550
Slope (°)	27	18	30
Age of plantations (year)	20	25	30
Stems per hectare (stems/ha)	620	410	280
Mean diameter (cm)	30.43	27.48	33.25
Mean height (m)	20.65	18.67	22.24
Total basal area (m^2·ha^{-1})	45.80	24.28	24.30

Table 3. Growing stock (m^3/ha) of *Tectona grandis* under different diameter classes on three different forest stands at various locations

Diameter class	Growing stork (m^3·ha^{-1})		
	Tuirial	Sairang	Phunchawng
10-20	13.0288	28.7349	3.1051
20-30	179.4053	29.0567	21.3411
30-40	217.8907	84.2399	96.0631
40-50	167.247	189.0604	87.4941
50-60	91.4364	106.7081	76.2618
Total	669.0082	437.8000	284.2652

The values of growing stock in the present study were comparable to the values recorded for other regions. In Costa Rica, 20- and 30-year old teak plantations exhibit 42.24 m^2/ha and 57.80 m^2/ha total basal area, respectively, and 695 m^3/ha and 770 m^3/ha growing stock, respectively (Perez 2005), which are higher than the values of this study for similar aged plantations. Hiratsuka et al. (2005) recorded that total basal area and growing stock values for 17 and 20 years old teak plantations at Lampang (North Thailand) were between 15.3–17.5 m^2/ha and 116.9–139.6 m^3/ha, respectively. The recorded values are lower than the values observed in this study for a 20-year old plantation at Tuirial (Tables 2, 3 and 4). A highly significant (<0.0001) positive power trend of regression correlation was observed volume *versus* height and diameter of the tree in all the studied sites.

In India, teak is grown in the States of Madhya Pradesh, Kerala, Maharashtra, Tamil Nadu, Uttar Pradesh, West Bengal, Bihar and Karnataka. Volume and yield tables for these states were established by Laurie and Ram in 1939 for the first time. Growth studies were also conducted in Andaman, Andra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh and Maharashtra. The yield figures in India at the age of 50, 70 and 80 years are 417 m^3, 510 m^3 and 539 m^3, respectively (Tiwari 1992). The volume of teak trees with dbh 60 cm and heights of 26, 35 and 50 m are 2.10 m^3, 2.86 m^3 and 4.11 m^3, respectively (Tiwari 1992). In the present study, the volume of teak trees in 50–60 cm diameter classes was recorded between 2.333 m^3–3.373 m^3, which is falling well within the reported range from India.

Table 4. Comparison of the present growing stock (m^3/ha) values of *Tectona grandis* with the recorded values for other regions

Variables	Stems per hectare ($stem \cdot ha^{-1}$)	Mean diameter (cm)	Mean height (m)	Age of plantations (years)	Total basal area ($m^2 \cdot ha^{-1}$)	Growing stock/Volume ($m^3 \cdot ha^{-1}$)	Reference
Australia	1023	13.4	12.5	12	14.9	62.3	Reid and Stephen (2001)
Costa Rica	336	40.2	28.7	20	42.2	695	
	333	47.8	32.4	30	57.8	770	Perez (2005)
DehraDun	-	-	-	-	-	372.4	Shreshta (2003)
Lampang	843.8	14.4	15.5	17	15.3	116.9	Hiratsuka et. al.
(North Thiland)	543	18.4	17.7	22	17.5	139.6	(2005)

The representation of population structure as percentage of individuals by size class is the only workable method to analyze the status of the forest. The population structure of the forest stands in different sites (Fig. 3) reveals that forest stand at Tuirial is younger than those at Sairang and Phunchawng. This is further explained that the population density in lower diameter classes is high in Tuirial and Sairang sites, suggesting that the perpetuation of *T. grandis* is ensured for a quite long time in these forest stands. However, individuals in Phunchawng site had a decreasing population both towards the lower and higher size classes, which may indicate that the population of individuals at this site is on the verge of extinction (Benton and Warnar 1976). Diameter class distribution is an important population characteristic, which is a consequence of both natality and mortality. The ratio of various diameter groups in a population also determines the reproductive structure (Odum 1971).

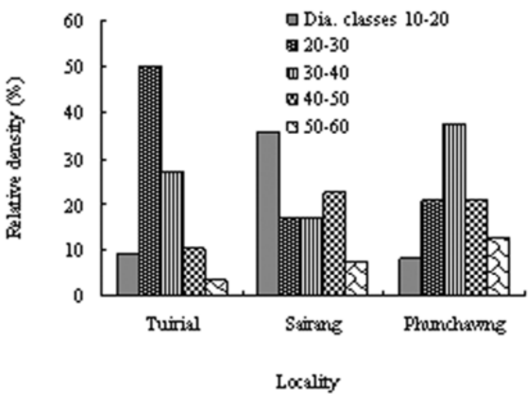

Fig. 3 Population structure of teak forest stands at different locations

Data presented in this study is important for the quantitative and qualitative evaluation of teak stands. Growth projections, stand density and total volume allow the construction of management scenarios for teak under any possible and logical circumstances. Further using of this data with larger databases, particularly with older plantations, is necessary to improve the goodness of fit and robustness, since current databases lack sufficient data at earlier and advanced ages. Nevertheless, the results of this study offer different management possibilities for teak forests in Mizoram to project the future biological asset value of the plantations as well. However, it should be used only as a guide, not as a prescription. An accurate estimation of the real saleable volume is necessary instead of the total standing volume of a plantation, for marketing projection purposes.

Availability of growing stock per unit area is important information needed to evaluate, monitor and harvest the available natural resource efficiently and for the judicious management of the forest for future planning. The information obtained by the collection of ground data, provides accurate results, which is of immense value in the current scenario of global warming, for the assessment of standing biomass to estimate the degree of carbon sequestration by the forest, as the volume-to-biomass method is considered as a better estimation method of forest biomass (Brown et al. 1997; Fang et al. 1998; Fang et al. 2001; Pan et al. 2004; Hu et al. 2007). Assessment of the potential of carbon storage in the forest requires species-level inventory of forests and plantations, as a consequence, it has become increasingly important to estimate the trunk volume and biomass for the purpose of carbon stock estimation. It has been recorded that a 5-year-old teak plantation contains 20–30 t C/ha (Potvin et al. 2004) and a 20-year-old plantation harbors 120 t C/ha (Kraenzel at al. 2003). Further, the growing stock data could be utilized for the stands' growth and yield models. The stand models use stand parameters such as basal area, volume, and parameters characterizing the underlying diameter distribution to simulate the stand growth and yield (Peng 2000).

Acknowledgement

The authors are thankful to both the anonymous reviewers of an earlier draft of this manuscript for their constructive criticism and valuable suggestions.

References

Bailleres H, Durand PY. 2000. Non-destructive techniques for wood quality assessments of plantation-grown teak. *Bois et Forêts des Tropiques*, **263**(1): 17–27.

Benton AH, Warner WE. 1976. Field biology and ecology. New York: Mc Graw Hill, Inc. 243pp.

Bermejo I, Cañellas I, San Miguel A. 2004. Growth and yield models for teak plantations in Costa Rica. *For Ecol Manage*, **189**: 97–110.

Bhat KM. 1995. A note on heartwood proportion and wood density of 8-year-old teak. *Indian Forester*, **121**(6): 514–516.

Bhat KM. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. *Bois et Forêts des Tropiques*, **263**(1): 6–15.

Bhat KM, Hwan Ok Ma. 2004. Teak growers unite. *ITTO Tropical Forest Update*, **14**(1): 3–5.

Bhatt A, Sharma CM, Khanduri VP. 2002. Growing stock variations in different *Cedrus deodara* forests of Garhwal Himalaya. *Indian Forester*, **128**(8): 903–916.

Brennan GK, Radomiljac AM. 1998. Preliminary observations on the utilization and wood properties of plantation teak (*Tectona grandis*) and African mahogany (*Khaya senegalensis*) grown near Kununurra, Western Australia. *Australian Forestry*, **61**(2): 120–126.

Brown S, Schroeder P, Birdsey R. 1997. Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. *For Ecol Manage,* **94**: 37–47.

Champion HG, Seth SK. 1968. *A revised survey of the forest types of India*. New Delhi: Govt. of India Publ. 404 pp.

Cochran WG. 1977. Sampling Techniques (Third Edition). New York: John Wiley and Sons , 428 pp.

Corona P, Marziliano PA, Scotti R. 2002. Top-down growth modeling: a prototype for poplar plantation in Italy. *Forest Ecol Manage*, **161**: 65–73.

Curtis JT, McIntosh RP. 1950. The interrelation of certain analytic and synthetic phytosociological characters. *Ecology*, **31**: 434–455.

Curtis JT, McIntosh RP. 1951. An upland forest continum in the prairie-forest border region of Wisconsin. *Ecology*, **32**: 476–496.

Fang JY, Wang GG, Liu GH, Xu SL. 1998. Forest biomass of China: An estimate based on the biomass-volume relationship. *Ecol Appl*, **8**(4): 1084–1091.

Fang JY, Chen A, Peng C, Zhao S, Chi L. 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. *Science*, **292**: 2320–2322.

Forest Survey of India. 1996. Volume Equations for Forests of India, Nepal and Bhutan, Dehradun, India.

Gray HR. 1956. The form and taper of forest trees stems. Imperial Forest Institute, Oxford University, Oxford Inst. Paper No. 32.

Hiratsuka M, Viriyabuncha C, Peawsa-ad K, Janmahasatien S, Akinobu S, Yusuke N, Chika M, Yasuo O, Yasushi M. 2005. Tree biomass and soil carbon in 17- and 22-year-old stands of teak (*Tectona grandis* L.f.) in northern Thailand. *Tropics*, **14**(4): 377–382.

Hu Haiqing, Liu Yuanchun, Jiao Yan. 2007. Estimation of the carbon storage of forest vegetation and carbon emission from forest fires in Heilongjiang Province, China. *Journal of Forestry Research*, **18**(1): 17−22.

Kaosa-ard A**.** 1981. Teak (*Tectona grandis* L.f.) - its natural distribution and related factors. *Natural History Bulletin of the Siam Society*, **19**: 55−74.

Knight D H. 1975. A phytosociological analysis of species rich tropical forests on Barro Colorado Island, Panama. *Ecological Monograph*, **45**: 249−259.

Kokutze AD, Baillères H, Stokes A, Kokou K. 2004. Proportion and quality of heartwood in Tongolese teak. *Forest Ecol Manage*, **189**: 37−48.

Kraenzel M, Castillo A, Moore T, Potvin C. 2003. Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. *Forest Ecol Manage*, **173**: 213−225.

Larson PR. 1963. Stem form development of forest trees. Forest Science Monograph 5, 1−42.

Laurie MV, Ram BS. 1939. Yield and stand tables for plantation teak. In: Indian Forest Record (n.s.) Silviculture 4-A, No. 1. Dehra Dun, India: Forest Research Institute.

Little S. 1983. Weibull diameter distribution for mixed stands of Western conifers. *Canadian Journal of Forest Research*, **13**: 85−88.

Longwood FR. 1961. Puerto Rican Woods: Their machining, seasoning and related characteristics. In: Agric. Handbook, U.S. Dep. Agric, 205: III, 98.

Maltamo M, Puumalainen JR, Paivinen R. 1995. Comparison of Beta and Weibull function for modeling basal area diameter distribution in stands of *Pinus sylvestris* and *Picea abies*. *Scandinavian Journal of Forest Research*, **10**: 284−295.

Misra R. 1968. *Ecology workbook*. New Delhi, India: Oxford and IBH Publishing Company, 244 pp.

Nair MNR, Chavan RR. 1985. Dimensional analysis of some wood parameters in eleven timber trees. *Indian Forester*, **111**(6): 410−417.

Nunifu TK, Murchinson HG. 1999. Provisional yield models of teak (*Tectona grandis* Linn F.) plantations in northern Ghana. *For Ecol Manage*, **120**: 171−178.

Odum EP. 1971. *Fundamentals of Ecology*. Philadelphia: W.B. Sounders Co.,. 574 pp.

Paivinen R. 1980. Estimation of stem-diameter distribution and stand characteristics. *Folia Forestalia*, **442**: 28 pp

Pan Y, Luo T, Birdsey R, Hom J, Melillo J. 2004. New estimates of carbon storage and sequestration in China's forests: Effects of age-class and method on inventory-based carbon estimation. *Climatic Change*, **67**: 211−236.

Pandey D. 1998. Forest plantation areas, 1995. Report of the FAO project GCP/INT/628/UK. 94 p.

Peng C. 2000. Growth and yield models for uneven-aged stands: past, present and future. *For Ecol Manage*, **132**: 259–279.

Pérez D. 2005. Stand growth scenarios for *Tectona grandis* plantations in Costa Rica. Academic dissertation, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, 77 pp.

Potvin C, Whidden E, Moore T. 2004. A case study of carbon pool under three different land-uses in Panama. *Climatic Change*, **67**: 291–307.

Priya PB, Bhat KM. 1999. Influence of rainfall, irrigation and age on the growth periodicity and wood structure in teak (*Tectona grandis*). *IAWA Journal*, **20**(2): 181–192.

Reid R, Stephen P. 2001. The Farmer's forest: Multipurpose forestry for Australian farmers. Birregurra, Australia: Australian Master Tree Grower Inc.

Seth SK, Yadav JSP. 1957. *Country Report from India on silviculture and management of teak*. Docum. 2nd Session FAO.

Shrestha HL. 2003. Comparative evaluation of multi-spatial resolution sata for timber volume estimation. Academic dissertation, International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands, 82 pp.

Takle GG, Majumdar RB. 1956. Increasing growth and regeneration of teak. *Indian Forester*, **82**(1): 8–21.

Tewari DN. 1992. *A monograph on teak (Tectona grandis)*. Dehra Dun, India: International book distributors..

Trockenbrodt M, Josue J. 1998. Wood properties and utilization potential of plantation teak (*Tectona grandis*) in Malaysia – A critical review. *Journal of Tropical Forest Products*, **5**(1): 58–70.

Troup RS. 1921. The silviculture of Indian trees. Vol. II. Oxford:.Clarendon Press, 697 pp.

Yamada M, Toma T, Hiratsuka M, Morikawa Y. 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E KS, Ranger J, Tiarks A, & Toma T. (Eds), Proc. Inter. Workshops on Site Management and Productivity in Tropical Plantation Forests, Congo and China, Pp. 213–226.